Neutralino Dark Matter vs Galaxy Formation

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Abstract. Neutralino dark matter may be incompatible with current cold dark matter models with cuspy dark halos, because excessive synchrotron radiation may originate from neutralino annihilations close to the black hole at the galactic center.

We report results obtained in [1], to which we refer for further details.

The composition of dark matter is one of the major issues in cosmology. A popular candidate for non-baryonic cold dark matter is the lightest neutralino appearing in a large class of supersymmetric models [2]. In a wide range of supersymmetric parameter space, relic neutralinos from the Big Bang are in principle abundant enough to account for the dark matter in our galactic halo [3].

A generic prediction of cold dark matter models is that dark matter halos should have steep central cusps, meaning that their density rises as $r^{-\gamma}$ to the center. Semi-analytical calculations find a cusp slope γ between ~ 1 [4] and 2 [5]. Simulations find a slope γ ranging from 0.3 [6] to 1 [7] to 1.5 [8]. It is unclear if dark matter profiles in real galaxies and galaxy clusters have a central cusp or a constant density core.

There is mounting evidence that the non-thermal radio source Sgr A* at the galactic center is a black hole of mass $M \sim 3 \times 10^6 \, M_\odot$. This inference is based on the large proper motion of nearby stars [9], the spectrum of Sgr A* (e.g. [10,11]), and its low proper motion [12]. It is difficult to explain these data without a black hole [13].

The black hole at the galactic center modifies the distribution of dark matter in its surroundings [14], creating a high density dark matter region called the spike – to distinguish it from the above mentioned cusp (see Fig. 1 for an illustration). Signals from particle dark matter annihilation in the spike may be used to discriminate between a central cusp and a central core. With a central cusp, the annihilation signals from the galactic center increase by many orders of magnitude. With a central core, the annihilation signals do not increase significantly.

Stellar winds are observed to pervade the inner parsec of the galaxy [10], and are supposed to feed the central black hole (e.g. [11,15]). These winds carry a magnetic field whose measured intensity is a few milligauss at a distance of $\sim$ 5pc from the galactic center [16]. The magnetic field intensity can rise to a few kilogauss at the Schwarzschild radius of the black hole in some accretion models for Sgr A* [17]. The existence and strength of a magnetic field in the inner parsec of the galaxy is crucial to our argument.

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In [1] we examine the radio emission from neutralino dark matter annihilation in the central spike. (Previous studies of radio emission from neutralino annihilation at the galactic center have considered an $r^{-1.8}$ cusp but no spike [18].) Radio emission is due to synchrotron radiation from annihilation electrons and positrons in the magnetic field around Sgr A*. Comparing the radio emission from the neutralino spike with the measured Sgr A* spectrum, we find that neutralino dark matter in the minimal supersymmetric standard model is incompatible with a dark matter cusp extending to the galactic center.

Since the strength and structure of the magnetic field around Sgr A* is only known to some extent (see discussion in [1]), we consider three simple but relevant models for the magnetic field and the electron/positron propagation. In model A, we assume that the magnetic field is uniform across the spike, with strength $B = 1$mG, and that the electrons and positrons lose all their energy into synchrotron radiation without moving significantly from their production point. In model B, we also assume that the magnetic field is uniform across the spike with strength $B = 1$mG, but that the electrons and positrons diffuse efficiently and are redistributed according to a gaussian encompassing the spike (we take the gaussian width $\lambda = 1$ pc). In model C, we assume that the magnetic field follows the equipartition value $B = 1\mu\mathrm{G}(r/\mathrm{pc})^{-5/4}$ (from ref. [17]) and that the electrons and positrons lose all their energy into synchrotron radiation without moving significantly from their production point. In addition, in model C, we neglect synchrotron self-absorption.

Under these assumptions, we obtain the following results.

If a dark matter cusp extends to the galactic center, the neutralino cannot be the dark matter in our galaxy. For example, let us assume that the halo profile is of the Navarro-Frenk-White form [7], namely $\rho \propto r^{-1}$ in the central region. Fig. 2 shows the expected radio fluxes $S_\nu = L_\nu/4\pi D^2$ at 408 MHz and the upper limit from [19]. The upper panel is for model A, the lower panel for model C. Results of model B are similar to those of model A. Irrespective of the assumption on the magnetic field or the $e^\pm$ propagation, all points in supersymmetric parameter space where the neutralino would be a good dark matter candidate are excluded by several orders of magnitude.

Conversely, if the neutralino is the dark matter, there is no steep dark matter cusp extending to the galactic center. We see this by lowering the cusp slope γ until the expected flux at 408 MHz decreases below the upper limit. We obtain a different maximum value $\gamma_{\max}$ for each point in supersymmetric parameter space. These values are plotted in Fig. 3 together with the range $0.3 \lesssim \gamma \lesssim 1.5$ obtained in cold dark matter simulations. The upper bounds $\gamma_{\max}$ are generally orders of magnitude smaller than the simulation results.

We conclude that neutralino dark matter in the minimal supersymmetric standard model is incompatible with a dark matter cusp extending to the galactic center. If there is a dark matter cusp extending to the center, we can exclude the neutralino in the minimal supersymmetric standard model as a dark matter candidate. Conversely, if the dark matter of the galactic halo is the lightest neutralino in the minimal supersymmetric standard model, we can exclude that a dark matter cusp extends to the center of the galaxy. Our conclusions are based on the presence of a magnetic field in the central parsec of our galaxy: if the magnetic field would be absent, there would be no synchrotron emission from annihilation electrons and positrons, and hence no synchrotron limits on neutralino dark matter and cuspy dark halos.

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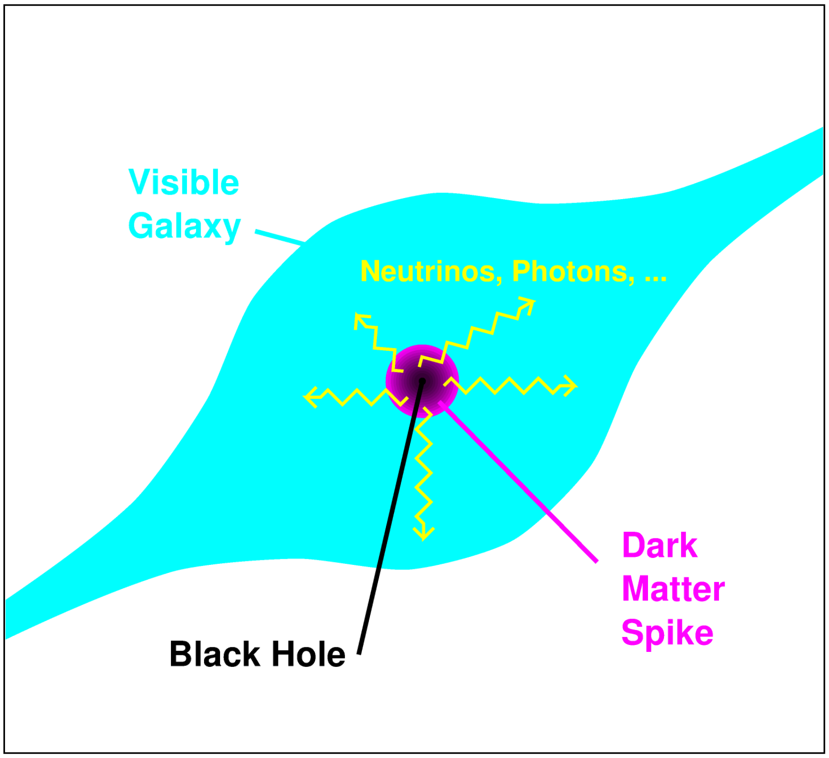

Fig. 1. Artist's impression of neutralino dark matter annihilations into neutrinos, photons, and other standard particles in the very dense dark matter spike which may form around the black hole at the galactic center.

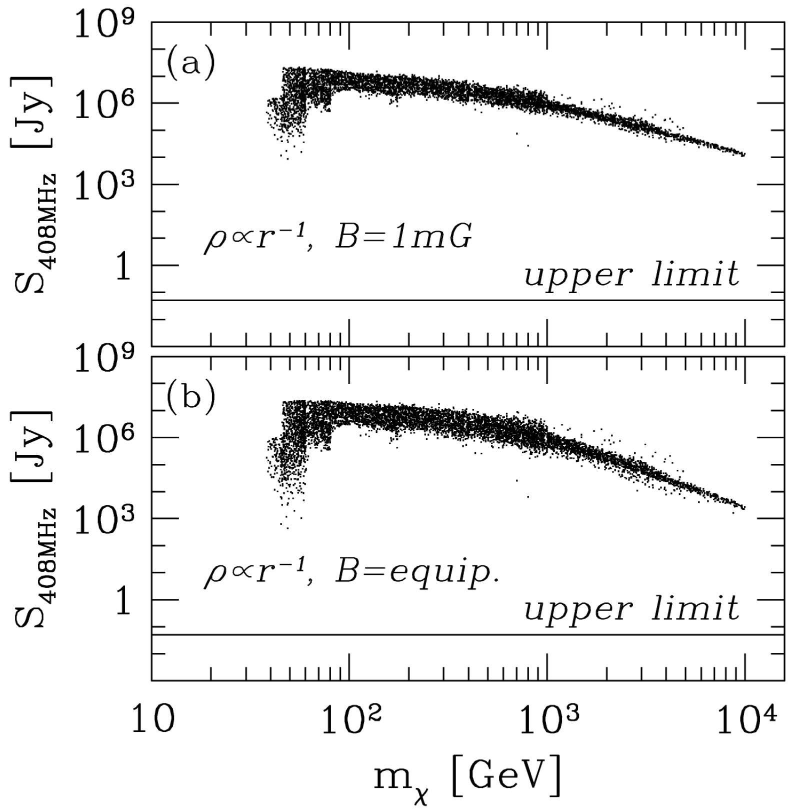

Fig. 2. Expected radio emission from the galactic center at 408 MHz from neutralino annihilations in the dark matter spike, assuming a Navarro-Frenk-White profile and (a) a uniform magnetic field of 1 mG, (b) a magnetic field at the equipartition value. All models exceed the present upper bound by several orders of magnitude.

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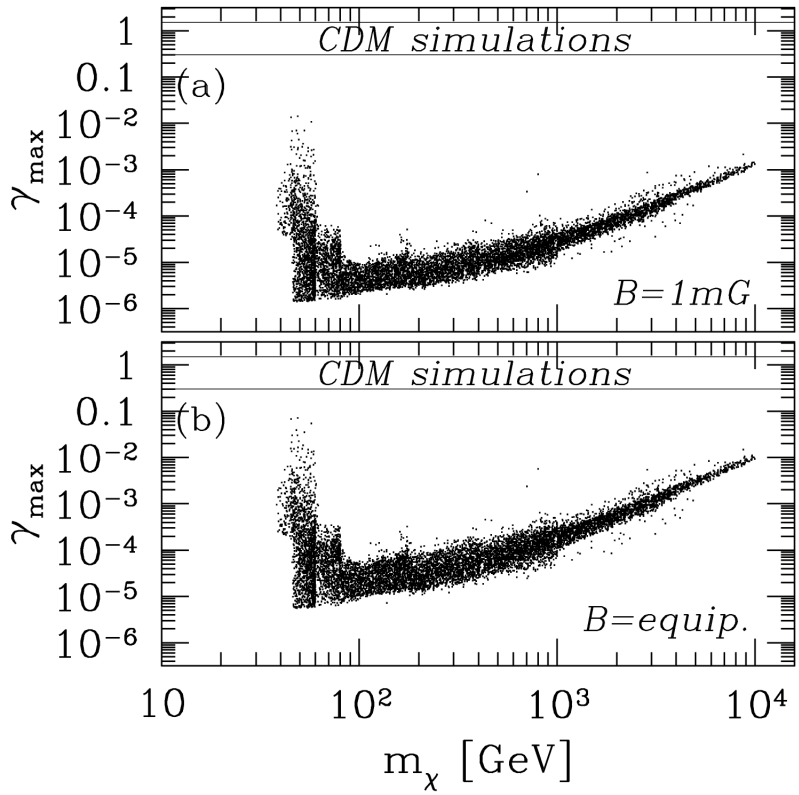

Fig. 3. Upper bound on the inner halo slope γ imposed by the constraint on the radio emission from the galactic center at 408 MHz, assuming (a) a uniform magnetic field of 1 mG, and (b) a magnetic field at the equipartition value. Each dot corresponds to a point in supersymmetric parameter space. The results of cold dark matter simulations are much higher than the upper bounds.